On The Scan Performance of Phased Array Fed Cylindrical Reflector With SuperQuadric Projected Aperture: PO/FFT Analysis

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ABSTRACT: The need for enhanced observational capabilities in a spaceborne microwave radar instrument to measure rainfall rates, vertical velocities with precipitation, and latent-heating profiles accurately and at sufficiently good resolution and spatial coverage throughout the tropics and mid-latitudes requires a large antenna with high-performance beam-scanning capabilities to avoid contamination by the surface clutter known as range ambiguity. This paper presents an antenna design for such an instrument with a novel phased-array-fed cylindrical reflector with a superquadric projected aperture. It is demonstrated that the far sidelobe levels (a source of noise and clutter) of a phased-array-fed cylindrical reflector can be monotonically reduced at a far angle from the peak of the beam with superquadric shaping of the projected antenna aperture. It is shown that a superquadric aperture-shaping parameter, n, range 2 to 4, can be used effectively to reduce far-sidelobe levels. This is demonstrated for a scan-beam range 0 to 16 degrees. It is found that impact of the shaping parameter, n, on the reduction of far-sidelobe levels is more pronounced as the beam is scanned away from nadir where it is mostly needed. The antenna-gain sensitivity to various shaping parameters, n, is given to help guide trade-offs in instrument design. Even though the proposed design capability is for multi-frequency operations at both 14 and 35 GHz and for multi-polarization, for the sake of brevity, results presented here will be limited to 14-GHz operation and vertical polarization only.

ANTENNA ANALYSIS AND GEOMETRY: The implemented simulation uses diffraction analysis procedures based on physical optics (PO) formulation [1]. The simulation considers that the illumination of the phased-array feeds of the cylindrical reflector shown in Figure 1a is generated by each element. With respect to individual feed elements in the array, the main reflector is considered to be in the far zone or far-field region. But with respect to the entire array, the main reflector may be in the near zone. For this reason, this approach ensures proper implementation of PO formulation of an array feed located in the near-field region of the reflector for the proposed design shown in Figure 1a. The current PO integral is evaluated using a two-dimensional fast Fourier transform (FFT) to ensure a proper integration of the high oscilliatory current. The formulation is accomplished by representing the projected aperture boundary in the x-y plane as a superquadric curve:

$$\left|\frac{x}{a}\right|^n + \left|\frac{y}{b}\right|^n = 1 \qquad (1)$$

where a, b are the semi-axes in the x and y direction respectively, and n is the parameter that provides the capability to control the shape of the curvature corners as shown in Figure 1b. It is evident from equation (1) that the superquadric representation allows modeling of numerous different projected aperture curve configurations through variation of the parameters, a, b, and n. Figure 1b illustrates the effect of various values of n on the curve geometry for the proposed antenna design with an aspect ratio of b/a=2. The cross section of the cylindrical reflector, shown in Figure 1a, is a parabola with diameter, D, equal to 6 m. The antenna length is 3 m. The antenna has a focal length to diameter ratio, F/D, of 0.4 as to keep the antenna assembly compact. The phased-array feed is located along the focal line in the y-z plane.

The amplitudes of the array-feed excitation taper symmetrically with distribution $\cos^2(\pi y/D)$, and the center element is fed by the largest amplitude. The scan beam is realized by phase progression of the elements. The inter-element spacing is 0.5 λ.

DISCUSSION AND RESULTS: Two cases are considered: In the first case a 233-element array fed cylindrical reflector, with the first element located at x=0, y=-1.25 m, and z=2.4 m, has a projected value of the antenna aperture shaping parameter of n=10. In this configuration, the antenna is under illuminated and we demonstrate an 8-degree scan (11-beamwidth) with the level of the first sidelobe remaining below approximately –30 dB relative to the peak of the beam as shown in Table 1 and Figure 2a. In the second case, we considered an array of 281 elements (for optimum antenna gain) that spreads along the whole length of the reflector with the first element located at x=0, y=-1.5 m and z=2.4 m, and n=10. In this case the beam-scan capability is relatively less and the far-sidelobe levels are relatively higher as shown in Figure 2b, and Table 2. Next, corrective measures are applied with superquadric aperture shaping to improve reduction of far-sidelobe levels. Figure 3 shows that a superquadric aperture shaping parameter, n, range 2 to 4 can be used effectively to reduce far-sidelobe levels. This is demonstrated for a scan-beam range of 0 to 16 degrees as shown in Figure 3a through 3f. It is found that the impact of the shaping parameter, n, on the reduction of far-sidelobe levels is more pronounced as the beam is scanned away from nadir as illustrated in Figures 3c/d, and 3e/f. For example, a value of n=2 results in a sidelobe-level reduction of 10 dB starting at 1 degree away from the peak of the antenna pattern for beam scan to 12 degrees from nadir as shown in Figure 3d. Reduction in sidelobe levels continue monotonically for an angle greater than 1 degree in elevation and azimuthal planes. Similar observations were made for beam scan to 16 degrees from nadir (sidelobe-level reduction greater than 10 dB starting at an angle of 1 degree in azimuth plane). The antenna gain sensitivity to various shaping parameters, n, is given in Table 2 to help guide the trade off in the instrument design.

Table 1. Scan performance of 233-element phased array fed cylindrical reflector for n=10.

Antenna Beam (V-POL or Y-polarization)	**Gain (dB)**	**Sidelobe* Level (dB)**	**Beamwidth Along Track (deg)**	**Beamwidth Cross Track (deg.)**
Beam 1 scan 0 deg.	53.47	-30.97	0.225	0.72
Beam 2 scan 4 deg.	53.45	-30.95	0.225	0.72
Beam 3 scan 8 deg.	53.39	-30.89	0.231	0.72
Beam 4 scan 12 deg.	53.45	-28.54	0.232	0.75
Beam 5 scan 16 deg.	52.72	-25.22	0.240	0.80

* relative to the peak of the beam

Table 2. Scan performance of 281-element phased array fed cylindrical reflector for various values of n.

	Antenna Gain		
SuperQuadric Projected Aperture	**Beam Scan 0°**	**Beam Scan 12°**	**Beam Scan 16°**
n=10	54.22 dB	53.72 dB	53.09 dB
n=4	54.20 dB	53.55 dB	52.87 dB
n=2	54.00 dB	53.04 dB	52.18 dB

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REFERENCES: [1] Y. Rahmat-Samii, Chapter 15, in Antenna Handbook, Y.T. Lo and S.W. Lee, eds., Van Nostrand Reinhold Company, New York, 1988.

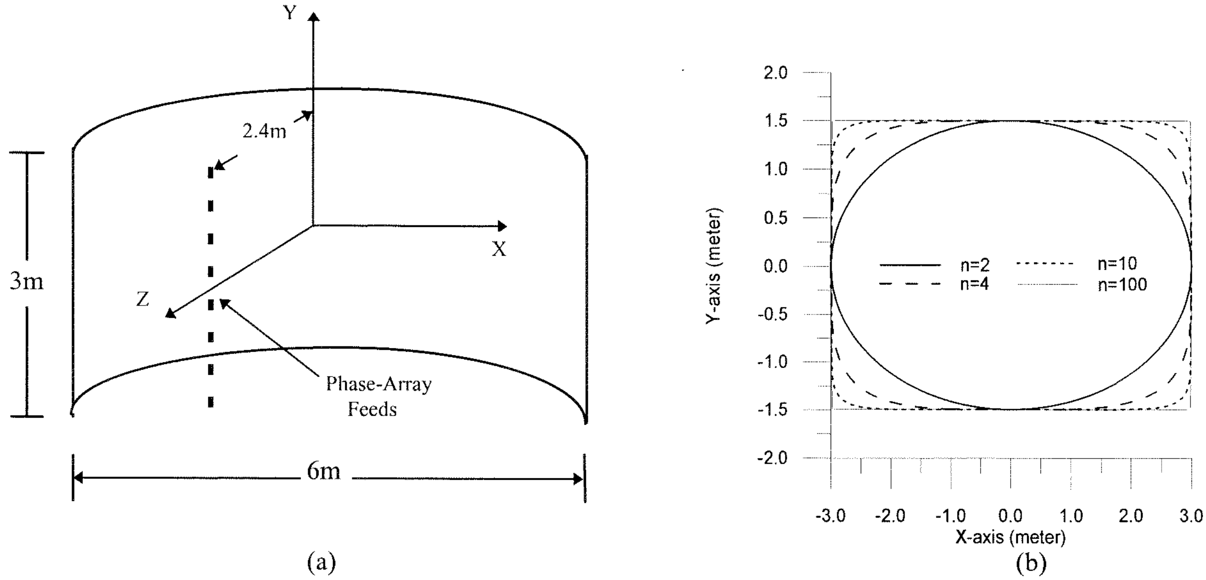

Figure 1. (a) Phased array fed cylindrical reflector. (b) Cylindrical reflector superquadric projected apertures in x-y plane.

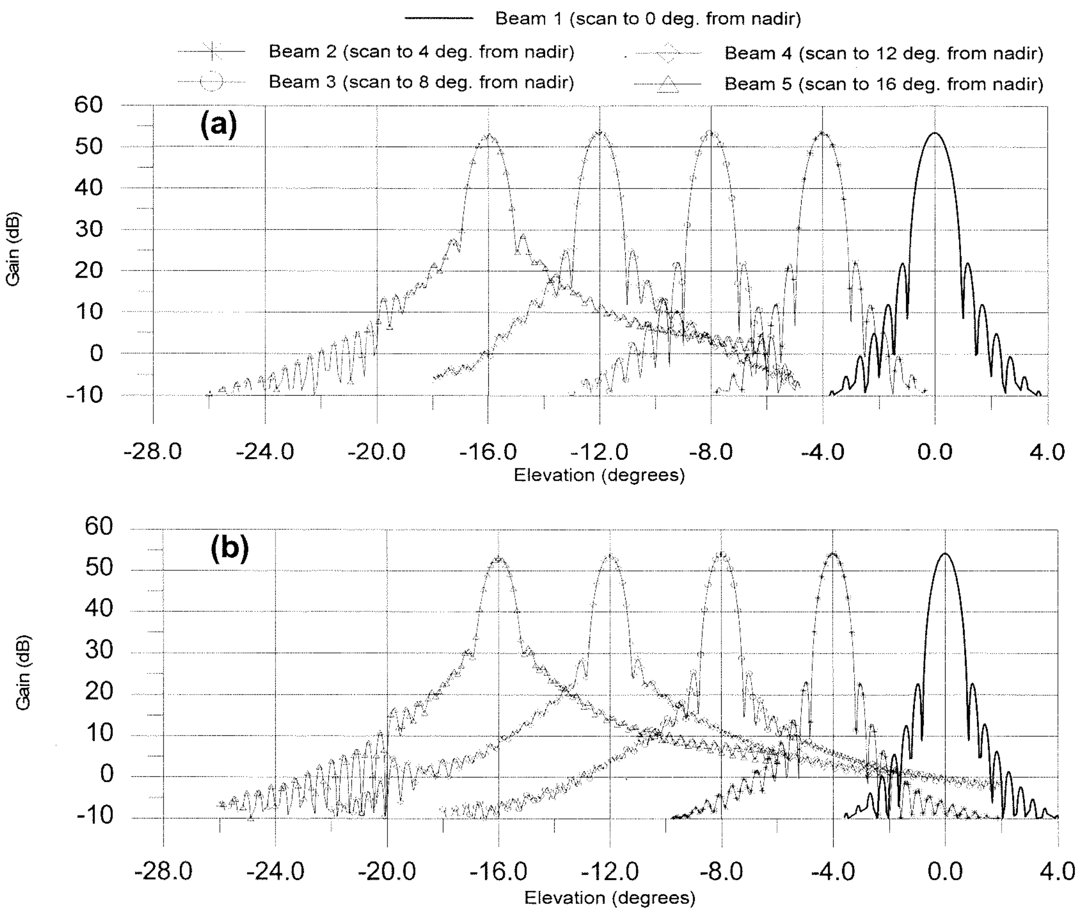

Figure 2. Scan beam performance of cylindrical reflector with superquadric projected aperture, n=10, for (a) 233-element array feeds; (b) 281-element array feeds.

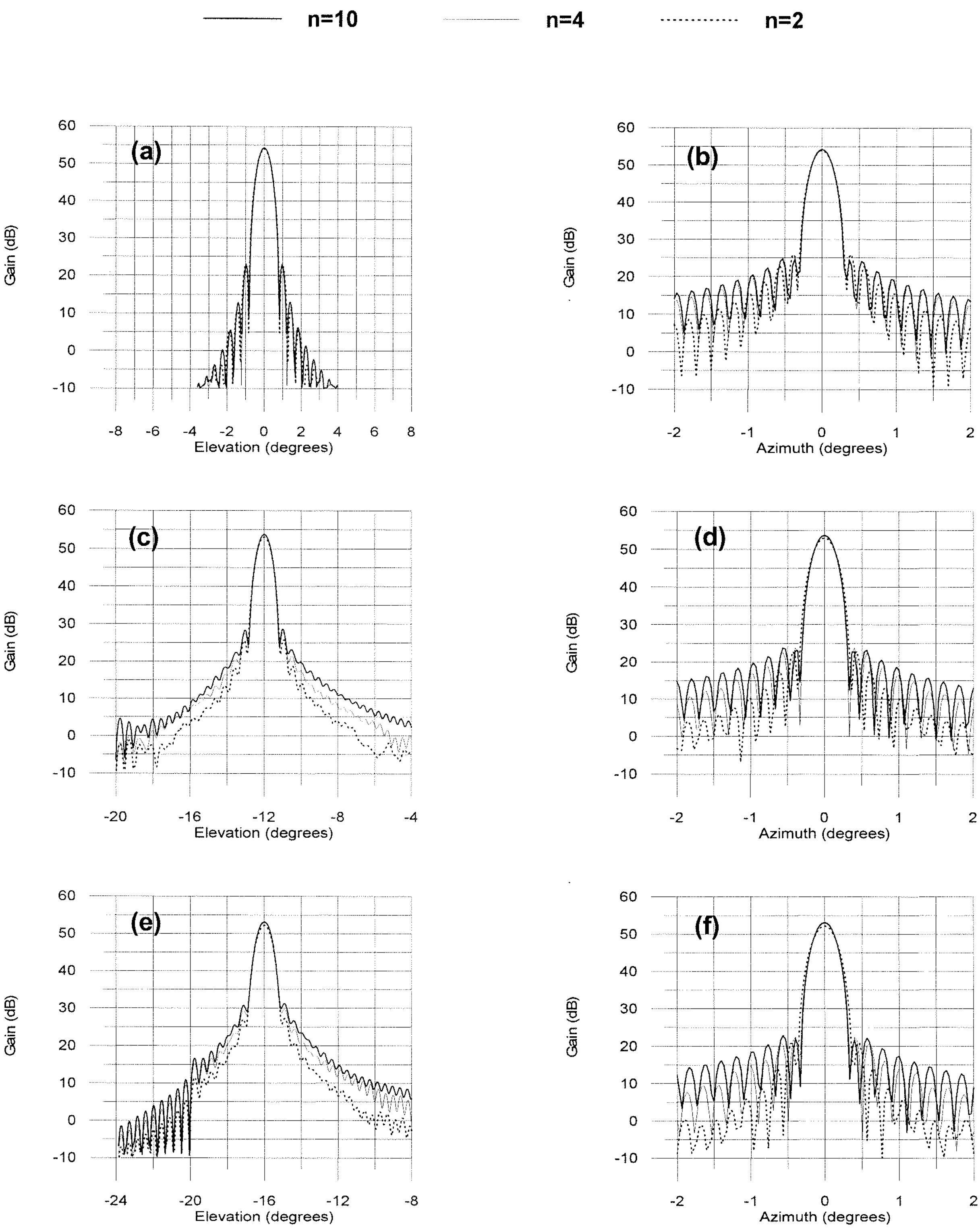

Figure 3. Effect of superquadric projected apertures shaping parameter, n, of a phased array fed cylindrical reflector on its scan beam radiation patterns for, (a) and (b) beam pointed at nadir/ 0 degrees scan; (c) and (d) beam scan to 12° from nadir; (e) and (f) beam scan to 16° from nadir. Note the azimuth cuts are taken through the beam peaks.